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ULTRASONIC WAVE PROBE
[CHOUONPA TANSHOKUSHI]

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Specification /549*

Title of the Invention

ULTRASONIC WAVE PROBE

Claims

An ultrasonic wave probe comprising an electro-acoustic transducer having piezoelectric material of polyvinylidene-fluoride or its copolymer, a first matching layer formed on one surface of the electro-acoustic transducer, and a second matching layer formed on the first matching layer, wherein the acoustic impedance density of the first matching layer is $1.6 \times 10^6 \sim 2.2 \times 10^6$ $Kg/S \cdot m^2$, and the acoustic impedance density of the second matching layer is $2.5 \times 10^6 \sim 3.4 \times 10^6$ $Kg/S \cdot m^2$.

Detailed Description of the Invention

This invention relates to an ultrasonic wave probe using an organic piezoelectric substance, and aims to provide the probe with high resolution and broad band capability.

There is a strong demand for an ultrasonic wave probe for ultrasonic wave diagnostic equipment that has a broad band and an excellent pulse response capability so that both deep and shallow sections of human anatomy can be diagnosed.

Although a conventional ultrasonic wave probe using piezoelectric ceramics for piezoelectric material has high conversion efficiency due to extremely large electro-mechanical coupling

* Number in the margin indicates pagination in the foreign text.

coefficient of the piezoelectric ceramics, its acoustic impedance matching with the human body and water is poor and consequently its frequency bandwidth is narrow.

Figure 1 shows an example of a configuration of a conventional ultrasonic wave probe using piezoelectric ceramics.

In Figure 1, 10 is a piezoelectric ceramics in Pb $(Zr,Ti)O_3$ family or $PbTiO_3$ family whose acoustic impedance density is $30x10^6$~$38x10^6$ $Kg/S \cdot m^2$, 11 is a first matching layer of glass or fused silica whose acoustic impedance density is $10x10^6$~$13x10^6$ $Kg/S \cdot m^2$, 12 is a second matching layer made from such materials as epoxy resin or acrylic resin whose acoustic impedance density is about $2.3x10^6$~$2.5x10^6$, 16 is an acoustic load such as a human body or water which has acoustic impedance density of about $1.5x10^6$ $Kg/S \cdot m^2$. Further, 13 is a packing layer of epoxy resin mixed with appropriate amount of tungsten powder. And 14 and 15 are electrodes for transmitting and receiving. /550

As is clear from Figure 1, the piezoelectric ceramics 10 has an acoustic impedance density of 20 times or more than that of test subjects such as the human body or water. For this reason, in order to obtain an impedance match, matching layers are provided so that the acoustic impedance density would become smaller going from the piezoelectric ceramics toward the test subject.

However, even with such ultrasonic wave probes having these matching layers, only about an 80% frequency ratio bandwidth at best

can be produced. With advancement in image processing technology and software for ultrasonic wave diagnostic equipment, probes with a much broader band are requested.

Recently, ultrasonic wave probes using polymeric piezoelectric film of polyvinylidene-fluoride, etc., have been introduced to counter these problems. Since this polymeric piezoelectric film has extremely small acoustic impedance density compared to piezoelectric ceramics, it has basically a much better acoustic impedance match with the human body compared to probes using piezoelectric ceramic materials, and is considered to be a good candidate for producing probes with a broad frequency bandwidth.

But the polyvinylidene-fluoride ("PVDF" hereafter) has an acoustic impedance density of 4.0×10^6 Kg/S·m^2 and electro-mechanical coupling coefficient of 0.22, while copolymer of vinylidene and vinyl fluoride, trifluoroethylene, tetrafluoroethylene, etc., ("PVDF copolymer") has an acoustic impedance density of 4.4×10^6 and electro-mechanical coupling coefficient of 0.30. Thus, even though they have a better acoustic match with the human body and water, they can only attain about 2.6~2.8 times the acoustic impedance density of the test subjects.

On the other hand, there has been some research performed on polymeric piezoelectric films having almost the same acoustic impedance density as water or the human body. However, these have smaller electro-acoustic conversion efficiency compared to PVDF or

PVDF copolymer.

Figure 2 shows a typical configuration of a conventional ultrasonic wave probe using PVDF.

In Figure 2, 20 is an organic piezoelectric body made from PVDF, 21 is a packing material composed from Cu, Fe, or epoxy mixed with tungsten powder, and 22 and 23 are transmitting/receiving electrodes.

Since the packing material 21 of this probe uses material whose characteristic acoustic impedance density is sufficiently larger than PVDF, its 1/4 wavelength behavior reaches almost the fixed end at the border with the packing material 21. An ultrasonic wave which is irradiated into the test subject 16, partially reflected, and returned, is picked up by the electrodes 22 and 23 as an electric signal.

However, as pointed out earlier, although the acoustic impedance of the PVDF is considerably smaller than the piezoelectric ceramics, the acoustic impedance is still 2.6~2.8 times larger compared to water. Thus, the impedance matching is not perfect against test subjects such as human body or water, its frequency ratio bandwidth cannot be sufficiently large, and it could not obtain sufficient sensitivity as the probe.

One way to resolve this problem was to add a 1/4 wavelength matching layer to the test subject side of the PVDF. Although this could have improved acoustic impedance matching and increased sensitivity, it was still difficult to widen the frequency bandwidth

sufficiently compared to the probe in Figure 2.

This invention is to resolve such problems with conventional probe above.

This invention aims to realize a probe with high sensitivity, a broad band, and excellent pulse response through a probe that has two layers of an impedance matching layer, each of which having appropriate acoustic impedance, that uses PVDF or PVDF copolymer for piezoelectric material.

Details are explained next using illustrating drawings.

Figure 3 shows the configuration of the ultrasonic wave probe of this invention.

In this figure, 20 is an organic piezoelectric body made from PVDF or PVDF copolymer, 21 is a packing material, 24 and 25 are respectively the first and second matching layer, 16 is a test subject like water or human body, and 22 and 23 are transmitting and receiving electrodes. The first and second matching layers, 24 and
25, are required to have appropriate impedance density for a broad /551
band area acoustic impedance matching, and they are set to about 1/4 wavelength of resonant frequency of the PVDF or PVDF copolymer.

As the packing material 21, in order to prevent ultrasonic waves from leaking from the organic piezoelectric material 20 through the packing material 21, it is desirable to use materials with sufficiently lower or sufficiently higher acoustic impedance density than the organic piezoelectric material 20.

The key factor of the ultrasonic wave probe under this invention shown in Figure 3 is the acoustic impedance density of the first and second matching layers. We have set the acoustic impedance density of the first matching layer to $2.5 \times 10^6 \sim 3.6 \times 10^6$ Kg/S·m^2, and the acoustic impedance density of the second matching layer to $1.6 \times 10^6 \sim 2.2 \times 10^6$ Kg/S·m^2.

With this, broad band impedance matching becomes possible for the first time, and the frequency bandwidth can be widened considerably compare to conventional ultrasonic wave probe. Further, compared to the ultrasonic wave probe shown in Figure 2, it can achieve a much higher sensitivity.

On the other hand if a matching layer whose acoustic impedance density is not within the above range, large ripples would be generated in the passing band, degrading the pulse response, and losing practical utility value.

Materials that can realize the acoustic impedance density of the first matching layer of this invention would include epoxy resin and nylon resin. Materials that can satisfy the second matching layer would include polyethylene, polyurethane, silicon resin, and polyimide resin.

Details of the embodiment of this invention with configuration shown in Figure 3 are explained next.

In Figure 3, the packing material 20 uses composite material that mixed appropriate amount of tungsten powder in epoxy resin to

achieve acoustic impedance density of 30×10^6 Kg/S·m^2, while the organic piezoelectric film uses PVDF, and the electrodes 22 and 23 use Al whose acoustic impedance density is relatively small at 16.9 Kg/S·m^2.

Since the acoustic impedance density of the packing material is considerably larger than the PVDF, the PVDF 20 would behave close to 1/4 wavelength sympathetic vibration.

Further, epoxy resin with acoustic impedance density of 2.72×10^6 Kg/S·m^2 is used for the first matching layer, and polyimide resin with acoustic impedance density of 1.82 $\times 10^6$ Kg/S·m^2 is used for the second matching layer.

Here, the thickness of the first matching layer and the second matching layer is set respectively to about 1/4 wavelength against the 1/4 wavelength resonant frequency of the PVDF piezoelectric film.

Further, the center frequency of this probe is designed be 4.5 MHz.

Figure 4 shows frequency characteristics that compare the probe of this invention against the conventional probe using piezoelectric ceramics shown in Figure 1, and against the probe using PVDF whose packing material is the same as this embodiment shown in Figure 2.

The frequency characteristics in Figure 4 show the reciprocation insertion loss characteristics that is produced when an ultrasonic wave is transmitted from the probe into the water, is reflected by an aluminum reflection plate located at 5 cm depth in the water, and is

received by the same probe. In Figure 4, 0 dB indicates the minimum insertion loss point of the conventional probe using piezoelectric ceramics shown in Figure 2. In this figure, the solid line shows frequency characteristics of the probe of this invention, the dashed line shows that of the conventional probe using piezoelectric ceramics, and the alternate long and short dashed line shows that of the probe using conventional PVDF. As is clear from this graph, the probe of this invention has attained a broad band. Further, pulse response characteristics, which can serve as an indicator of resolution capability, of 3 types of ultrasonic wave probes were evaluated. When an impulse is inputted to the probe and the time that it takes the trailing to decay to 30 dB was examined, as compared to the conventional transducer shown in Figure 1, the conventional probe shown in Figure 2 was 1/1.9, while the transducer under this invention was 1/2.3.

On the other hand, when a material with characteristic impedance density outside of the range of this invention is used for the matching layer, a large ripple occurred in the passing band, and the trailing of the impulse response did not improve too much compared to the conventional probe using piezoelectric ceramics. /552

As explained above, the probe under this invention, having the optimal double matching layers, can produce favorable acoustic impedance matching with the human body over the broad band, and can easily produce high sensitivity, a broad band, and high resolution

capability.

Although this embodiment has shown a case where the packing material was made from material whose acoustic impedance density was much larger than the PVDF, even when the packing material made from materials such as cork onion skin paper, sonite, or silicon rubber with considerably smaller acoustic impedance is used, the optimal value of the impedance of the acoustic matching layer is not influenced at all except for the fact that the PVDF does 1/2 wavelength sympathetic vibration.

Brief Description of the Figures

Figure 1 shows the constitution of the conventional ultrasonic wave probe using piezoelectric ceramics. Figure 2 shows the constitution of the ultrasonic wave probe using an organic piezoelectric material such as conventional PVDF. Figure 3 shows the constitution of the ultrasonic probe under this invention. Figure 4 is a frequency characteristics graph of ultrasonic wave probes. In these figures, 10 represents piezoelectric ceramics, 11 and 12 are matching layers, 13 represents packing, 14 and 15 are electrodes, 16 is an acoustic load, 20 is an organic material such as PVDF, 21 is packing, 22 and 23 are electrodes, and 24 and 25 are matching layers.

Figure 1

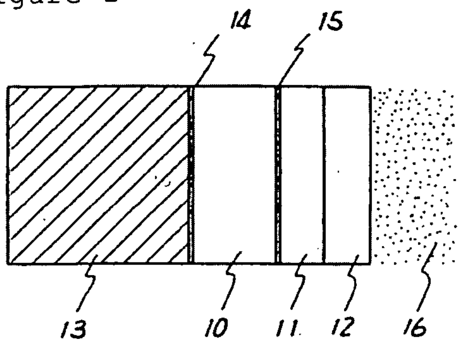


Figure 2

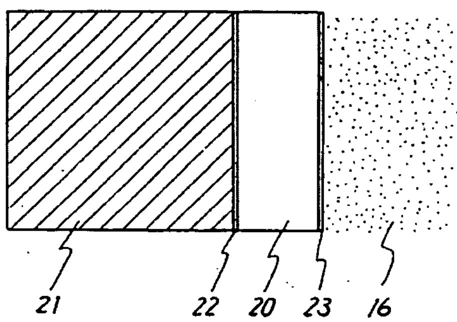


Figure 3

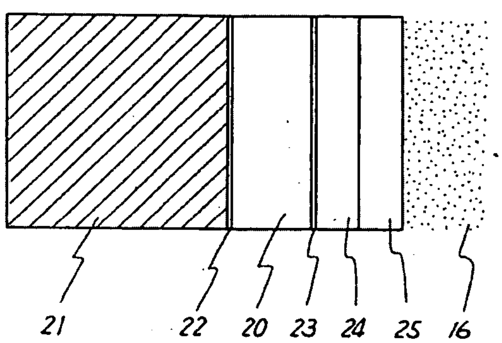
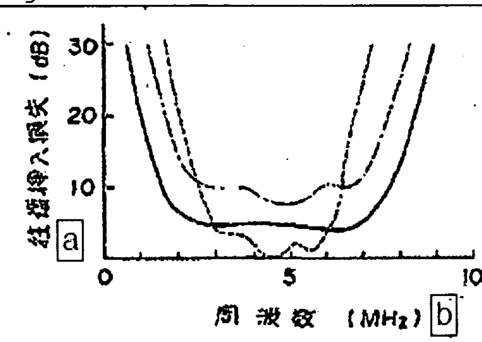


Figure 4 /553



Key:
a) Reciprocation insertion loss (dB);
b) Frequency (MHz).